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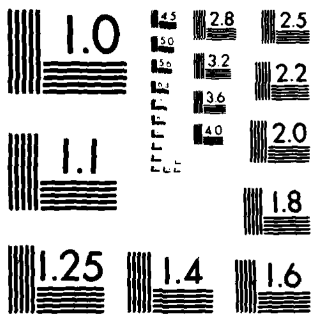

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EFFECT OF PROPAGATION DISTANCE ON AIRCRAFT FLYOVER SOUND DURATION

JERRY D. SPEAKMAN

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In the past, NOISEMAP and other aircraft noise contouring programs incorporating single event, time-integrated measures such as Sound Exposure Level (SEL) or Effective Perceived Noise Level (EPNL) assumed that the sound duration for flyovers doubled for each doubling of the distance between the source and a receiver. This simplifying assumption considers only the losses due to the spherical divergence of a sound wave as it propagates over distance.

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Mathematically this meant that in calculating SEL or EPNL versus distance functions, a "duration" term was introduced that was proportional to multiplying the logarithm of the ratio in propagation distances between two points by a coefficient of 10.

Controlled level flyover noise tests were conducted on A-10, C-135A, C-141, E-3A, F-5E, F-15 and F-18 aircraft to directly measure sound duration as a function of propagation distance. Data were also acquired during a dedicated series of C-130E actual takeoffs and landings.

Our findings show the duration coefficient varies between 5 and 7 for different aircraft types. Clearly the old coefficient of 10 is wrong. Data are included that also show that the sound attenuation mechanisms controlling this duration coefficient are basically independent of the frequency content of the aircraft noise.

Accordingly, the military aircraft noise data base (NOISE-FILE) used by NOISEMAP was changed in February 1980 to reflect a sound duration coefficient of 6. This improvement in the modeling of sound duration typically reduces airbase noise contour areas by 10% to 30%.

PREFACE

This study was performed by the Biodynamic Environment Branch, Biodynamics and Bioengineering Division, Air Force Aerospace Medical Research Laboratory, under Project/Task 723107, Technology To Define and Assess Environmental Quality Of Noise From Air Force Operations.

The author gratefully acknowledges Mr. John Cole for his guidance during this study and reviewing this report, Messers. Robert Lee and Robert Powell for their assistance in acquiring the raw data, Messers. Keith Kettler and Fred Lampley of the University of Dayton Research Institute for assistance in field test support and data processing, and Mrs. Norma Peachey for assistance in preparing this report.

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INTRODUCTION

Since 1971 the Air Force Aerospace Medical Research Laboratory has been actively developing and improving NOISEMAP, a fully computerized procedure for generating cumulative noise exposure contours around airbases. NOISEMAP has become the cornerstone of the Department of Defense Air Installation Compatible Use Zone (AICUZ) program to discourage community encroachment that could inhibit aircraft operations. In addition, NOISEMAP is a crucial element in environmental noise assessments of proposed mission realignments, beddown of new systems, and a key factor in defense of noise-related lawsuits.

NOISEMAP generates contours of equal noise exposure in terms of Day-Night Level (DNL) by coupling an aircraft unique single-event noise characteristic data base with a comprehensive modeling program which accounts for the average busy day aircraft flight and ground runup activity at an airbase. During the evaluation of this cumulative exposure metric, the concept was firmly established that for discrete noise events, such as aircraft flyovers, the signal duration strongly influences the judged noisiness or relative acceptability. As such, the single event noise measure which is summed on an equal energy basis to obtain the DNL is the Sound Exposure Level (SEL), defined as being the time-integrated A-weighted level. NOISEMAP and all other nationally and internationally used noise contouring programs incorporating such a time integrated measure assume the duration of the signal doubles for each doubling of the distance between the receiver and the noise source. This simplifying assumption considers losses due to spherical divergence of a sound wave as it propagates over distance, but neglects losses due to atmospheric absorption and forward flight effects on the directivity characteristics of the source. Based on this original assumption, computing single-event noise level versus distance functions for any time integrated measure (e.g., Sound Exposure Level or Effective Perceived Noise Level) involves introducing a "duration" term that is proportional to multiplying the logarithm of the ratio in propagation distances between two points by a coefficient of 10.

Because of the sparsity of available measured data on the duration of flight noise signals over long propagation distances, we recently conducted controlled level flyover noise tests, using a variety of both large and small military aircraft having both turbojet and turbofan engines. Large transport type aircraft measured were C-135A (turbojet), C-141 (turbofan), and E-3A (turbofan). The small attack and fighter-type aircraft measured were A-10 (turbofan), F-5E (turbojet), F-15 (turbofan), and F-18 (turbofan). In these tests, six microphones were positioned perpendicular to the flight track of the aircraft and measurements were made of the sound durations over propagation distances, ranging from a couple of hundred feet to over 5000 feet for various engine power settings and airspeeds.

In addition to these tests, noise data previously collected during a dedicated series of C-130E (turboprop) actual takeoffs and landings were analyzed. In the C-130E tests the microphones were positioned directly under the aircraft flight path such that sound duration measurements were made over propagation distances of 100 to 2200 feet.

RESULTS AND CONCLUSIONS

During data reduction, sample integration periods of 0.25 to 0.50 sec were used in determining both time-integrated and maximum values. Figures 1 and 2* for the C-130E aircraft are representative of our findings. The data points are the field measured sound durations

(differences between the SEL values and ALM, the maximum A-weighted values) expressed in dB re 1 sec. plotted on a logarithmic scale of the minimum slant distance to the aircraft. The duration coefficients listed (6.2 for the takeoffs and 6.3 for the landings) are the slopes of the regression lines through the data points.

Table 1 lists the results of our flyover tests on the other aircraft and the C-130E (takeoffs and landings combined as one data set). These data clearly show that the original assumed value of 10 for the duration coefficient was wrong. A value of 10 is overly conservative and will typically cause predicted SELs and EPNLs at propagation distances of 4000 to 5000 feet to be 2 dB or 3 dB higher than what we have measured.

Table 1. MEASURED SOUND DURATION VRS DISTANCE

Aircraft Type	Slant Distance (ft)	Number of Flights	Duration Coefficient
A—10	257 — 5012	11	7.1
C—130	111 — 2246	10	6.3
C—135A	284 — 2378	5	6.5
C—141E	355 — 4991	4	4.8
E—3A	575 — 5032	11	5.8
F—5E	235 — 5038	7	5.8
F—15	476 — 5140	11	5.1
F—18	526 — 5775	8	6.0
			Avg 5.9 DB, $\sigma = 0.7$

Table 1 also shows that the duration coefficient varies from 5 to 7 for the different types of aircraft tested. To acquire and analyze the field measured data necessary to derive aircraft-type dependent duration coefficients for all of the different types in the active inventory would be costly. Implementing such aircraft-type dependent values would in all likelihood yield only minute changes in airbase noise contours for any realistic mixture of aircraft type and operational conditions. Accordingly, the Air Force in February 1980 adopted the single, nominal value of 6 as the duration coefficient used in generating SEL versus distance functions for all military aircraft.

In addition to these findings on the effect of propagation distance on sound duration in terms of the A-weighted measure (SEL), we also analyzed the data in one-third octave bands to determine if there were any frequency dependent characteristics. Figures 3 through 19 show these results for eight flyovers of the F-15 aircraft for the one-third octave bands 50 Hz to 2000 Hz. These figures show the data for the following F-15 flyovers: Flight 21 @ military power @ 350 knots, Flight 22 @ military power @ 380 knots, Flight 23 @ military power @ 380 knots, Flight 27 @ approach power @ 175 knots, Flight 28 @ approach power @ 160 knots, Flight 29 @ cruise power @ 290 knots, Flight 31 @ military power @ 380 knots, and Flight 32 @ military power @ 360 knots. The data points plotted in each figure are the differences in dB re 1 sec. between the field measured time-integrated sound pressure level (SPL_{INT}) and the maximum sound pressure level (SPL_{MAX}) at each microphone site (minimum slant distance from the aircraft) for each flyover. The duration coefficient (B = slope of the regression line through the data points), the correlation coefficient (r), and the coefficient of determination (r^2) are listed on each figure.

*Figures 1-20 are located after the text.

Table 2 lists the sound duration coefficients, Figures 3 to 19, for the F-15 aircraft as well as those duration coefficients for the other types of aircraft. In general, Figure 20 shows that except for the one-third octaves at 125,160, and 200 Hz the duration coefficients are virtually independent of frequency. We believe that the somewhat higher values shown from 125 to 200 Hz are due to ground reflection effects present in the raw, field measured data. Table 3 summarizes the sound duration coefficients found by using SEL-ALM and the cases of SPL_{INT} – SPL_{MAX} with and without bands 21, 22, and 23.

Table 2. SOUND DURATION COEFFICIENTS AS FUNCTION OF FREQUENCY

Frequency Hz	A-10	C-135A	C-141	E-3A	F-5E	F-15	F-18	All Aircraft	All Aircraft Corr. Coeff.
50		9.2	5.0	6.4		6.7		6.2	.804
63		7.2	4.2	4.8		6.8		5.5	.746
80		7.5	5.2	4.3	8.7	6.4		5.7	.792
100	9.8	6.0	4.2	4.1	5.7	5.7	4.9	5.8	.736
125	10.5	9.0	5.2	6.2	8.3	8.9	9.7	8.4	.850
160	7.4	8.2	8.0	6.1	5.9	9.1	10.6	8.2	.840
200	6.5	9.5	7.2	6.3	6.3	7.2	10.0	7.6	.836
250	6.0	8.1	5.4	3.3	5.3	6.3	7.3	6.1	.768
315	6.3	7.8	6.6	4.1	7.9	7.4	7.9	6.8	.775
400	6.8	6.0	4.0	4.1	7.2	6.4	7.0	6.2	.748
500	5.7	6.4	5.2	4.6	8.1	6.4	5.8	6.1	.733
630	5.8	5.5	4.3	5.1	7.2	5.6	5.6	5.6	.701
800	5.7	5.5	4.8	5.4	6.4	5.2	5.1	5.3	.713
1000	5.8	5.0	4.4	5.0	6.9	5.3	4.8	5.6	.712
1250	6.5	6.6	4.6	5.9	7.7	5.3	5.5	6.4	.733
1600	7.2	6.2	5.5	5.1	6.4	6.0	5.4	6.4	.735
2000	7.7	6.1	8.0	5.5	6.4	5.6	5.1	6.6	.748
2500	9.8	5.8	7.1	5.1	7.0		5.1	7.0	.694
3150	7.1	5.5	6.1	6.3	6.2		5.3	6.4	.675
4000	6.0	5.0	5.9	6.5	6.2		4.7	6.3	.730
Average	7.1	6.8	5.5	5.2	6.9	6.5	6.5	6.4	
σ	1.5	1.4	1.2	0.9	0.9	1.1	1.6	0.8	

Table 3. FIELD MEASURED SOUND DURATION COEFFICIENTS

	SEL – ALM	$SPL_{INT} - SPL_{MAX}$ (Without Bands 21, 22, 23)	$SPL_{INT} - SPL_{MAX}$ (All Bands)
A-10	7.1	6.9	7.1
C-135A	6.5	6.5	6.8
C-141	4.8	5.3	5.5
E-3A	5.8	5.0	5.2
F-5E	5.8	6.9	6.9
F-15	5.1	6.1	6.5
F-18	6.0	5.7	6.5
All Aircraft Average	5.9	6.1	6.4
σ	.8	.8	.7

We conclude that the sound duration coefficient can be assumed to be 6 for all aircraft-types in generating DNL noise exposure contour maps for the purposes of assessing environmental impact and planning compatible land uses. While this study only involved fixed-wing aircraft, our finding should also be applicable to rotary-wing aircraft.

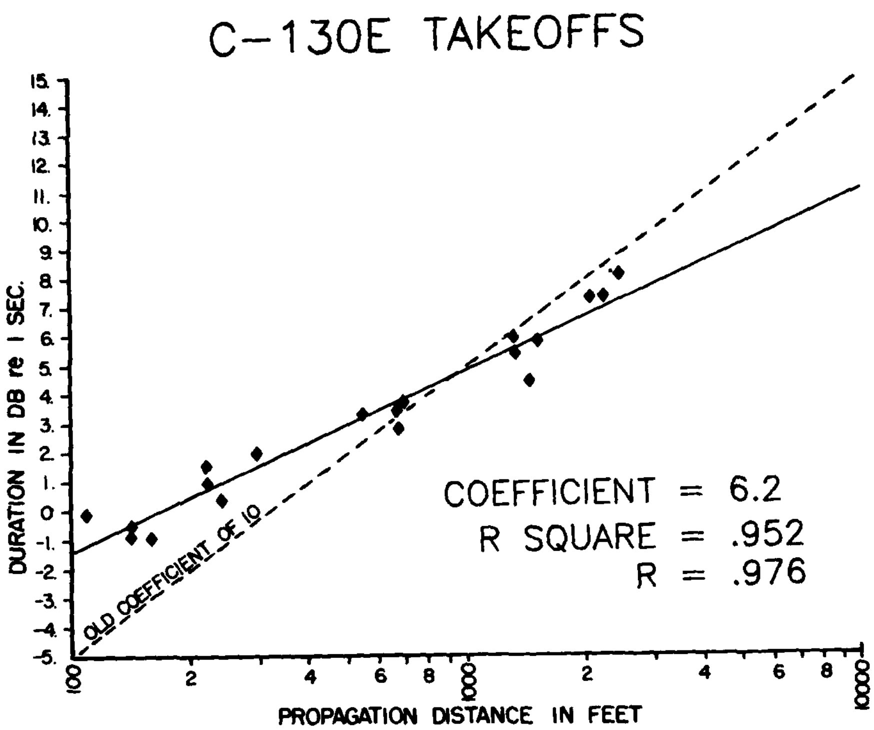

Figure 1. C-130E TAKEOFFS

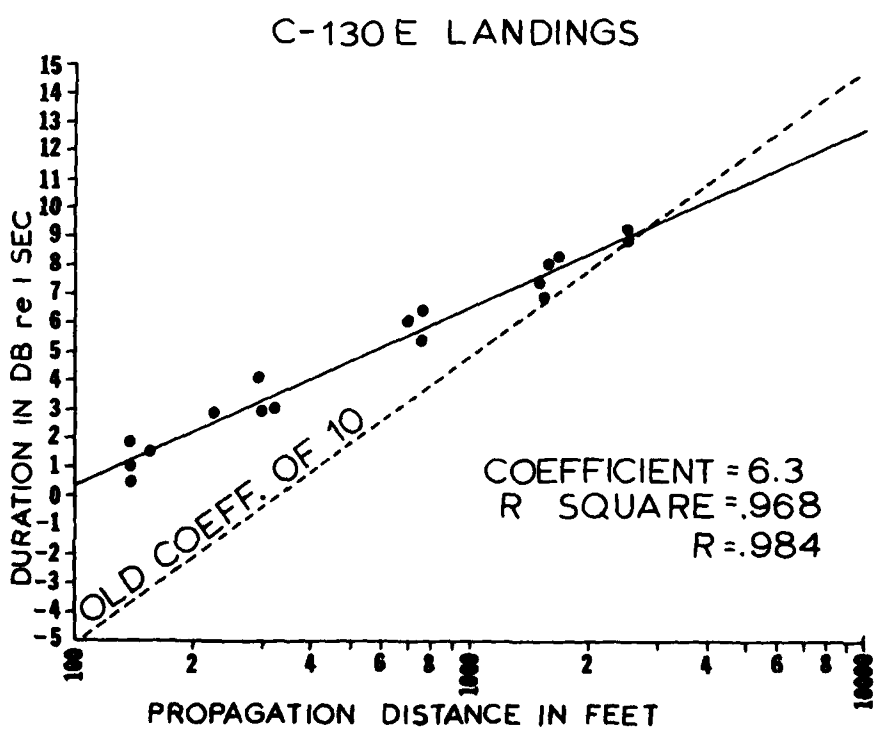

Figure 2. C-130E LANDINGS

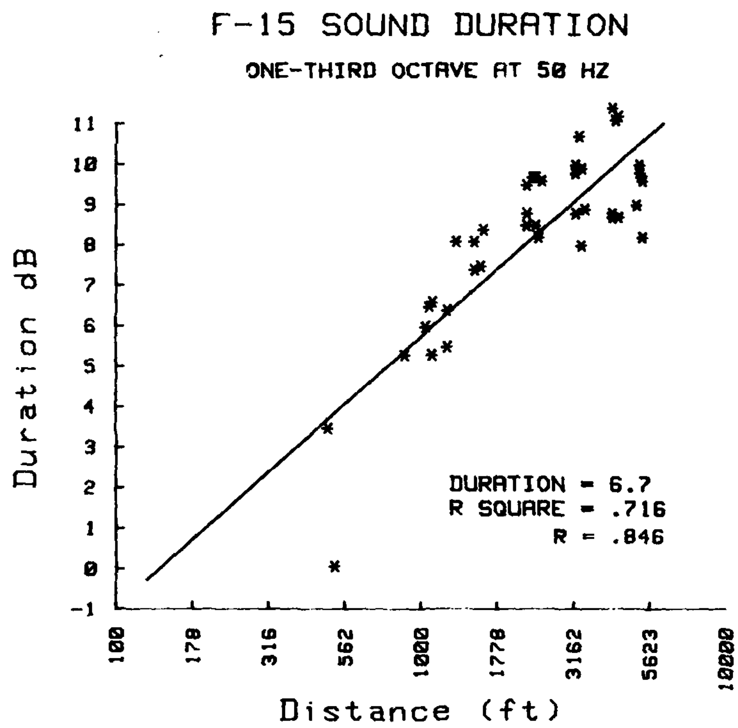

Figure 3. F-15 SOUND DURATION AT 50 Hz

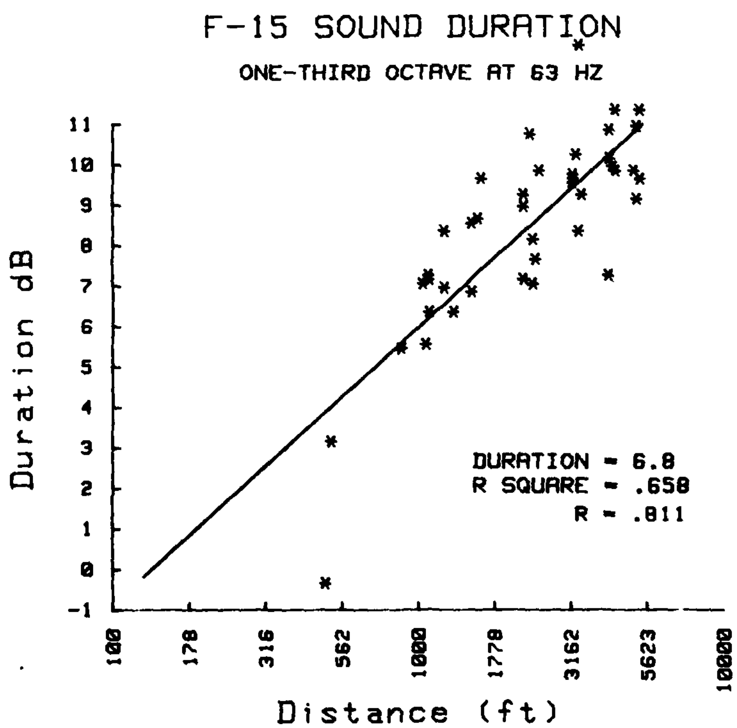

Figure 4. F-15 SOUND DURATION AT 63 Hz

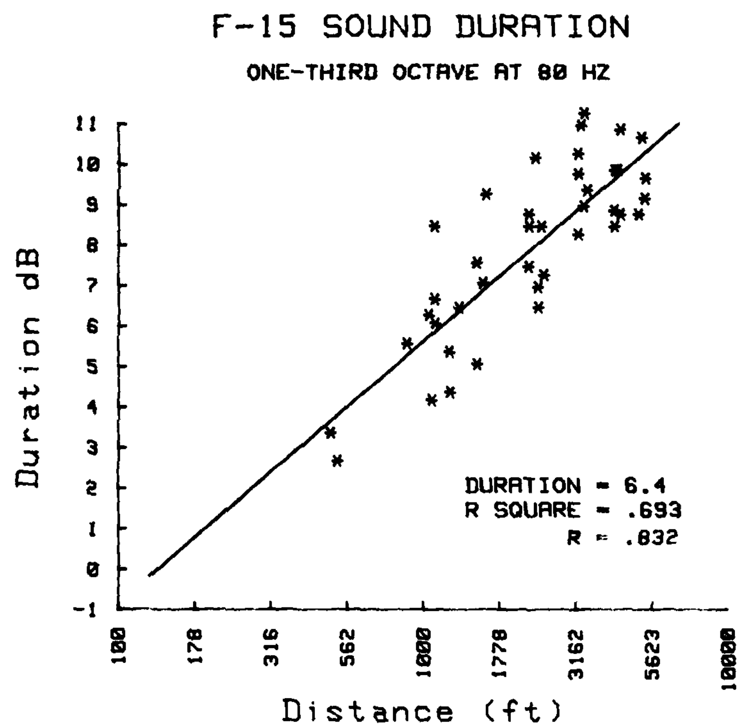

Figure 5. F-15 SOUND DURATION AT 80 Hz

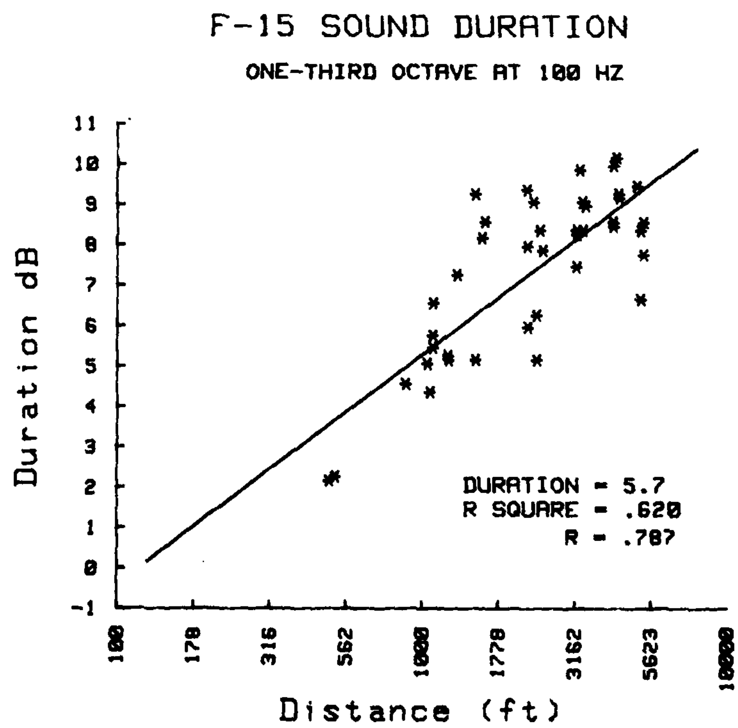

Figure 6. F-15 SOUND DURATION AT 100 Hz

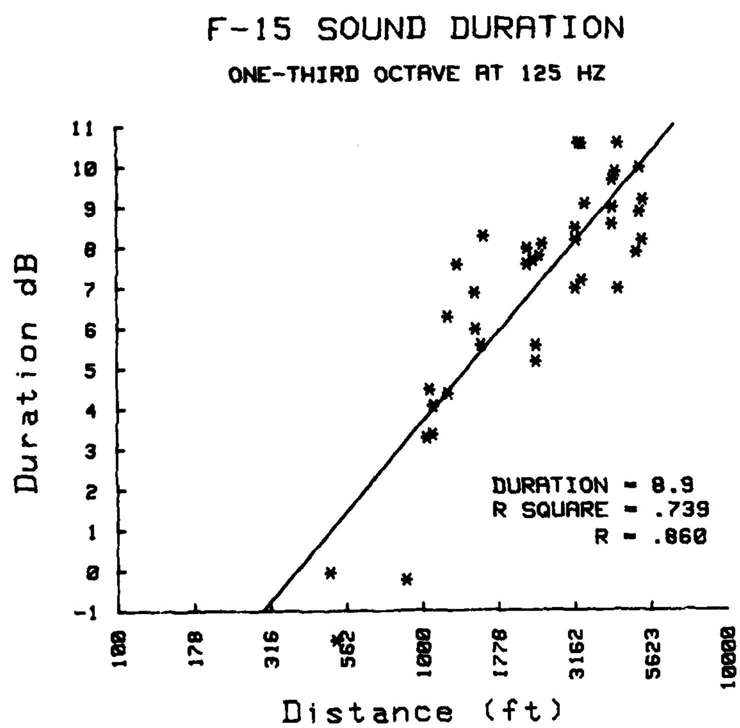

Figure 7. F-15 SOUND DURATION AT 125 Hz

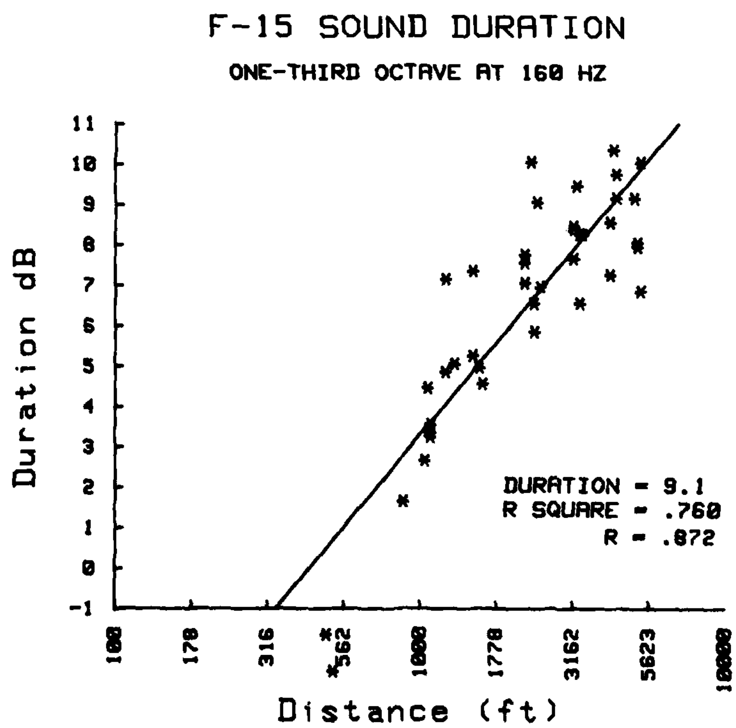

Figure 8. F-15 SOUND DURATION AT 160 Hz

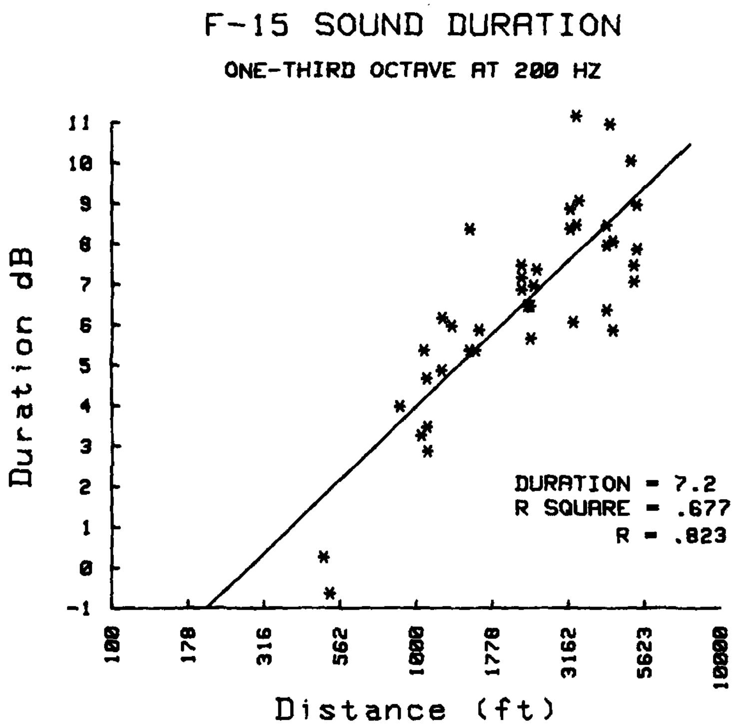

Figure 9. F-15 SOUND DURATION AT 200 Hz

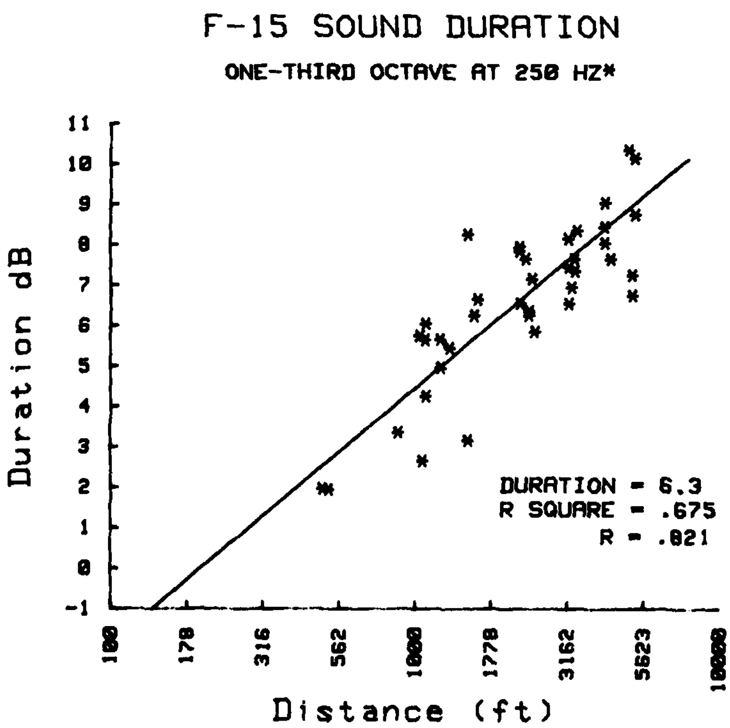

Figure 10. F-15 SOUND DURATION AT 250 Hz

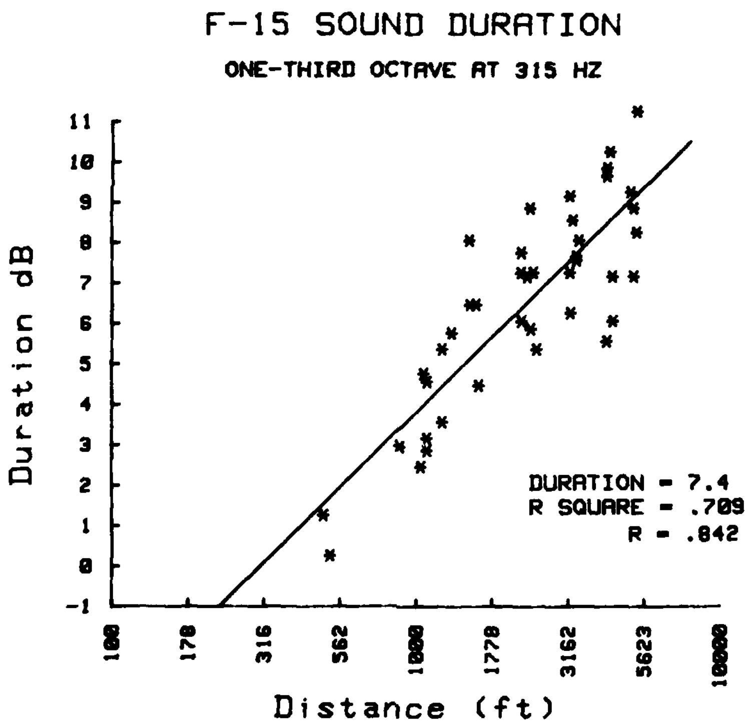

Figure 11. F-15 SOUND DURATION AT 315 Hz

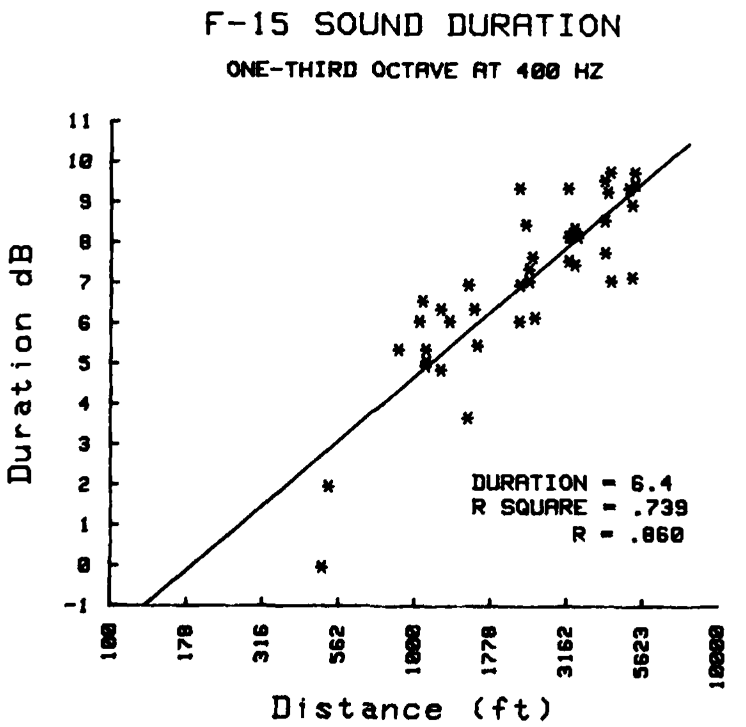

Figure 12. F-15 SOUND DURATION AT 400 Hz

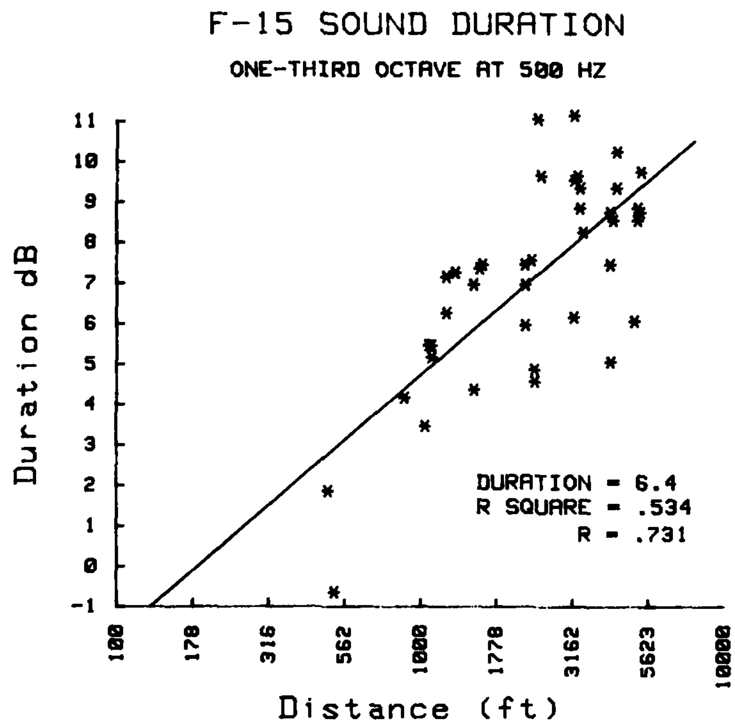

Figure 13. F-15 SOUND DURATION AT 500 Hz

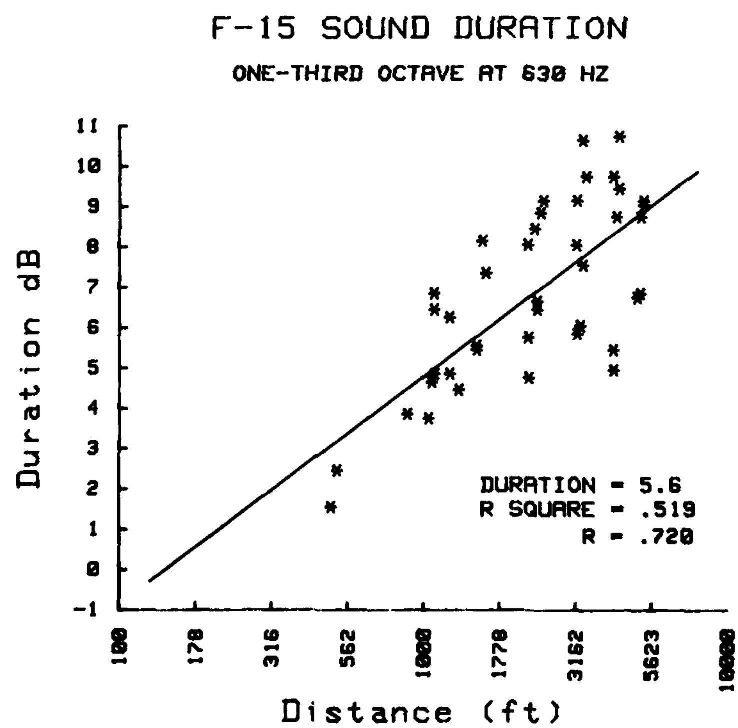

Figure 14. F-15 SOUND DURATION AT 630 Hz

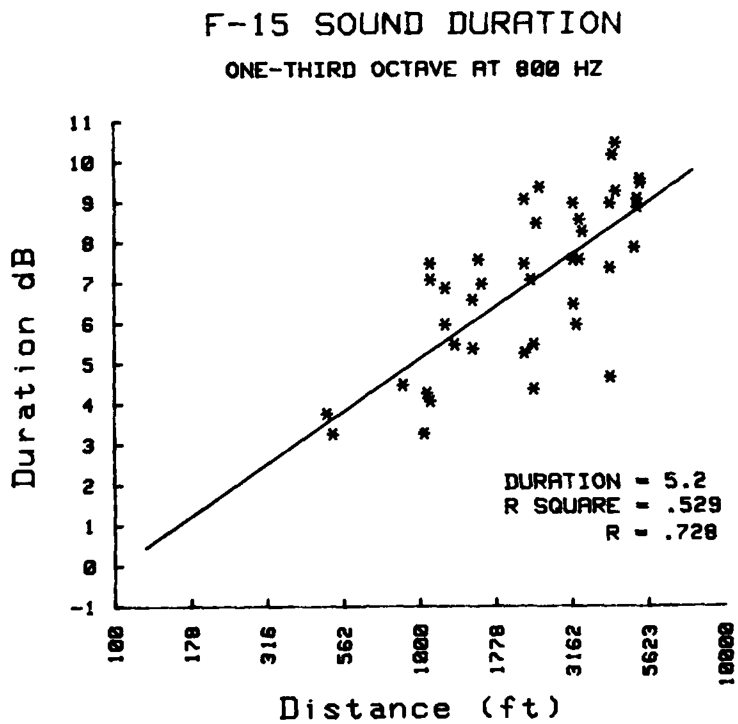

Figure 15. F-15 SOUND DURATION AT 800 Hz

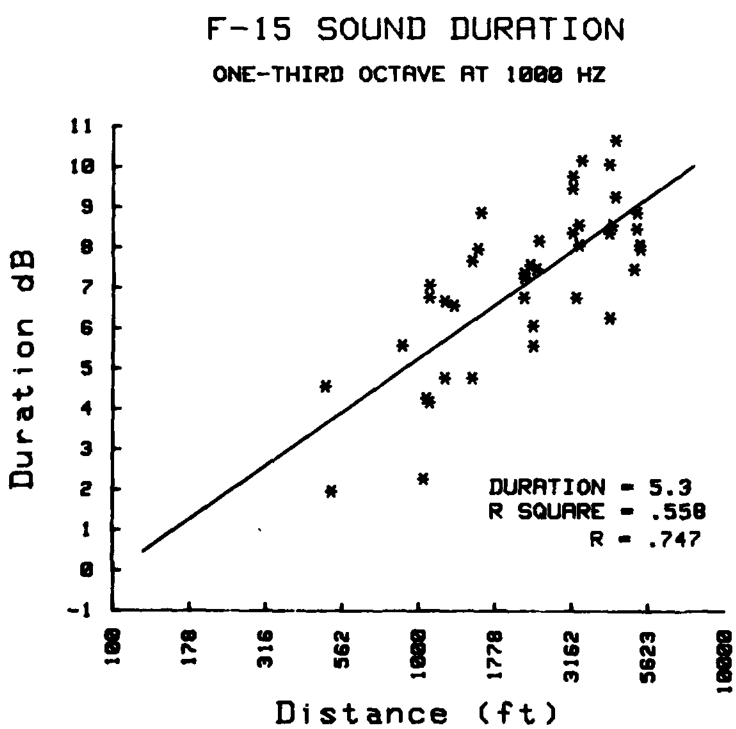

Figure 16. F-15 SOUND DURATION AT 1000 Hz

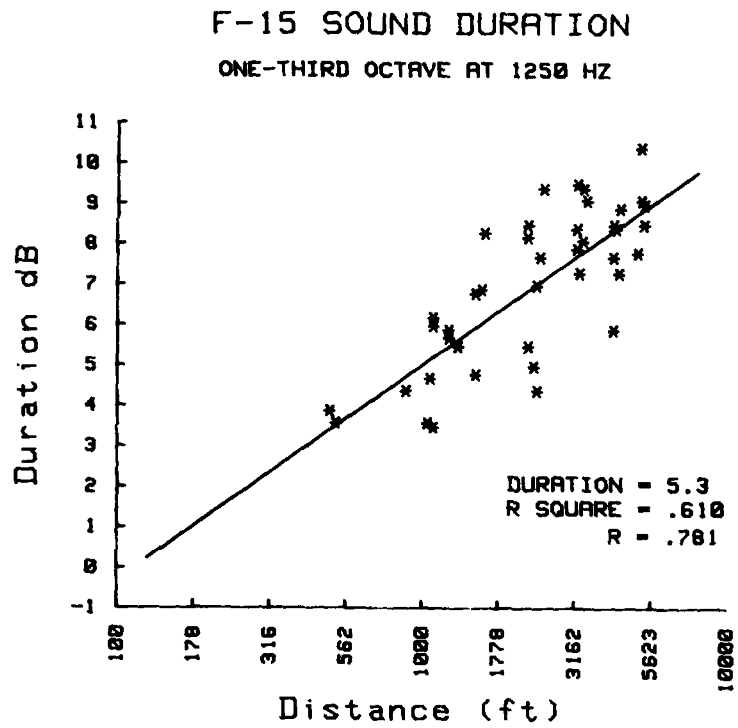

Figure 17. F-15 SOUND DURATION AT 1250 Hz

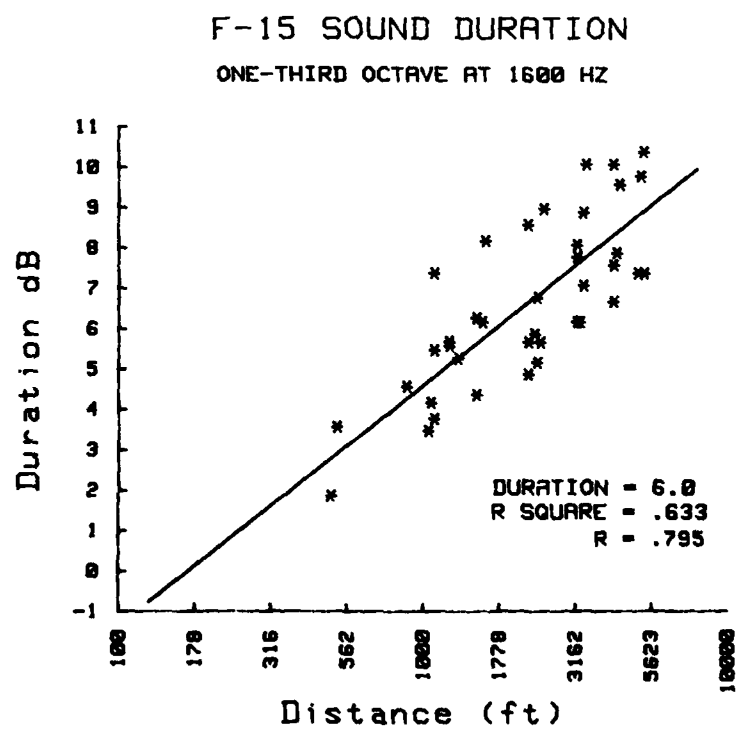

Figure 18. F-15 SOUND DURATION AT 1600 Hz

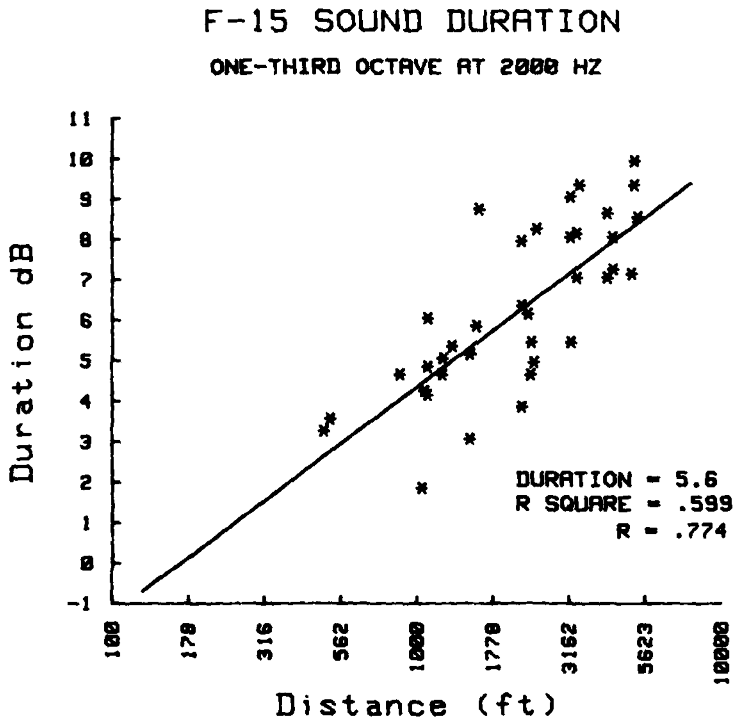

Figure 19. F-15 SOUND DURATION AT 2000 Hz

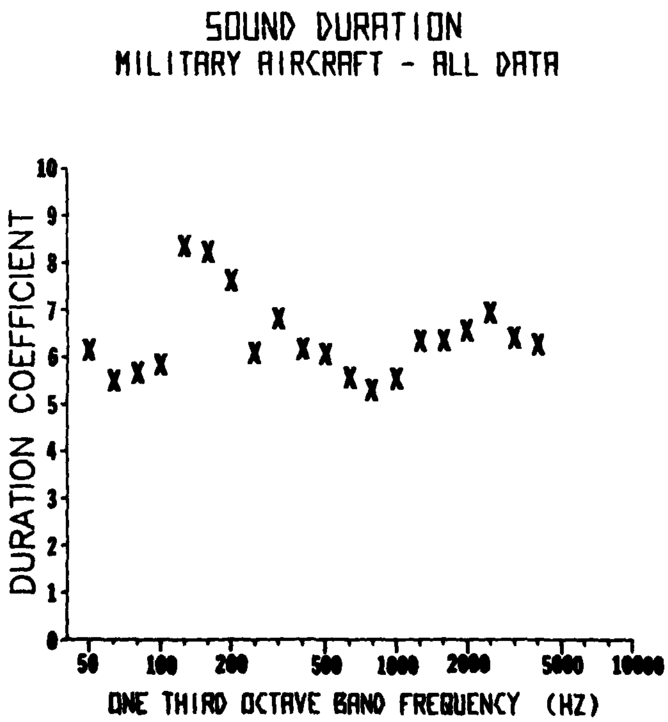

Figure 20. SOUND DURATION, MILITARY AIRCRAFT - ALL DATA

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